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(54) WEAR-RESISTANT ALUMINUM ALLOY CAST ROD AND ITS PRODUCTION

(57)Abstract:
PURPOSE: To produce the title high-quality Al alloy cast rod having excellent wear resistance and forgeability by casting, cooling, and heat-treating the Al alloy contg. Si, Cu, Mg, Fe, Mn, and Sr as the essential components and having a specified composition under specified conditions.

CONSTITUTION: When an Al alloy contg., by weight, 7.5W22.0% Si, 3.0W7.0% Cu, 0.3W1.0% Mg, 0.25W1.0% Fe, 0.25W1.0% Mn, and 0.005W0.1% Sr as the essential components is cast, the casting temp. is controlled to 670W850°C, and then the cast is cooled at a cooling rate of ≥5°C/sec from 670°C to 544°C and at a rate of ≥10°C/sec from 560°C to 544°C. The ingot after casting is heat- treated at (450W510°C)×(2W12hr). The diameter of the circumscribed circle of the Si phase and the inevitably generated crystallized material of every kind is controlled to ≤20μm, and the interval between the branches of aluminum dendrite is controlled to ≤10μm. By this method, an Al alloy cast rod having excellent wear resistance and mechanical properties and suitable for forging is obtained.

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WEAR-RESISTANT ALUMINUM ALLOY CAST ROD AND PROCESS FOR THE PRODUCTION THEREOF

[Tai-mamosei aluminium gokin chuzo bo oyobi sono seizo hoho]

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Claims /1*

1. A wear-resistant aluminum alloy cast rod characterized by being an aluminum alloy cast rod containing Si: 7.5-22.0 wt% (% by weight, same below), Cu: 3.0-7.0%, Mg: 0.3-1.0%, Fe: 0.25-1.0%, Mn: 0.25-1.0% and Sr: 0.005-0.1% as an essential component; controlling the diameter of the circumscribed circle of the Si phase and various crystallized materials unavoidably generated below 20 μm; and at the same time, spacing of the branches of aluminum dendrite below 10 μm.

2. A process for the production of a wear-resistant aluminum alloy cast rod characterized by, in the case of casting an aluminum alloy containing Si: 7.5-22.0%, Cu: 3.0-7.0%, Mg: 0.3-1.0%, Fe: 0.25-1.0%, Mn: 0.25-1.0% and Sr: 0.005-0.1% as an essential component, setting the casting temperature in the range of 670-850°C; cooling from 670-554°C at a cooling rate faster than 5°C/sec, at the same time, from 560-554°C at a cooling rate faster than 10°C/sec; and carrying out a thermal treatment of (450-510°C) x (2-12 h) after casting.

Detailed explanation of the invention

Industrial application field

This invention pertains to a process for the preparation of an aluminum alloy cast rod. In particular, it pertains to an aluminum alloy cast rod suitable for forging and process for the production of it.

Prior art

For automobile parts, etc., requiring wear resistance as well as light weight, Al-Si type eutectic alloys such as A4032, etc., have been being used previously, and in general, various parts are prepared with continuous casting-extrusion processes. However, those materials are not sufficiently satisfactory to

* [Numbers in right margin indicate pagination of the original text.]

answer those demands of a high degree of wear resistance in recent years, and there is also a problem of inferior strength.

On the other hand, A390 alloy, which is an Al-Si type hypereutectic alloy, has been known for excellent wear resistance, but the extrusion is not possible in the case of this alloy, at the same time, the /2 forgeability is inferior, and consequently, it has been used as a casting material.

However, in the fields of automobile parts, etc., in recent years, there are trends of using cast rod-forged aluminum materials instead of the previous cast or cast-extrusion materials, and it has been strongly desirable to develop an aluminum alloy having excellent forgeability as well as excellent wear-resistance.

Problems to be solved by the invention

Therefore, there have been various proposals. For example, Japanese Koku Patent Application No. Sho 60[1985]-51017 discloses a material with the wear-resistance and forgeability improved by adding Cu, Mg, Fe, Mn, Ti, etc., to an Al-7.5-13.5% Si system, and Japanese Kokai Patent Application Nos. Sho 60[1985]-197838 and 61[1986]-26741 disclose materials with restricted eutectic crystal size, Si-Mn-Fe compound size, α-Al phase size, etc., controlled by adding Cu, Mg, Fe, Mn, etc., to a Al-7.5-22% Si system.

However, in the production of aluminum cast materials of those proposals, there was a problem of generation of large Al-Fe-Mn-(Si) compounds at the time of casting, at the same time, in the forging after casting, the forgeability was inferior because the crushing of crystallized substances and formation of microscopic crystalline particles observable in the previous extrusion stage could not be anticipated, and furthermore, there were also problems of reduced fatigue life, etc.

The objective of this invention is to eliminate the above shortcomings of the prior art and provides an art enabling to produce a high-quality aluminum alloy cast rod having excellent forgeability and mechanical properties as well as wear resistance.

Means to accomplish the objective

To achieve the above objective, the inventors of this invention found that any improvements in wear resistance, forgeability, etc., were limited because in those aluminum alloys for forging described above, the refinement of Al-Fe-Mn-Si compounds, Si primary crystal, eutectic Si compounds, etc., generated at the time of casting to microscopic sizes was limited to a certain extent since they were crystallized.

The inventors of this invention found also that if a portion of the crystallized products could be eliminated, allowing the remaining crystallized products to be refined further into microscopic particles, forging-material and wear-resistance requirements became satisfactory, and they studied further by carrying out experiments with respect to chemical components, casting conditions, etc.

As a result, they found that if a suitable amount of Sr was added to the above Al-Si alloy, and the casting was carried out under specific conditions, the Al-Fe-Mn-Si compounds and Si primary crystal among those crystallized products could be effectively refined and eliminated, the eutectic Si could be refined to a microscopic size, and the spacing of the aluminum dendrite could be reduced, and furthermore, if a specific thermal treatment was carried out after casting, the other crystallized products such as those of Al-Cu, Al-Mg-Si type, etc., contained in the cast rod were eliminated, and at the same time, the granulation of the eutectic Si was increased, thereby improving the forgeability, and they arrived at this invention.

Specifically, the wear-resistant aluminum alloy cast rod of this invention is characterized by being an aluminum alloy cast rod containing Si: 7.5-22.0 wt% (% by weight, same below), Cu: 3.0-7.0%,

Mg: 0.3-1.0%, Fe: 0.25-1.0%, Mn: 0.25-1.0% and Sr: 0.005-0.1% as an essential component; the diameter of the circumscribed circle of the Si phase and various crystallized materials unavoidably generated was kept below 20 µm, and at the same time, spacing of the branches of aluminum dendrite was kept below 10 µm.

Furthermore, the process for the production of a wear-resistant aluminum alloy cast rod of this invention is characterized by, in the case of casting an aluminum alloy of the above composition, setting the casting temperature in the range of 670-850°C; cooling from 670-554°C at a cooling rate above 5°C/sec, at the same time, from 568-554°C at a cooling rate above 10°C/sec; and carrying out a thermal treatment of (450-510°C) x (2-12 h) after casting.

This invention is explained in detail as follows.

The reasons for chemical component limits in the aluminum alloy of this invention will be explained first.

Si is an essential component for wear resistance; if it comprises less than 7.5%, the effect is not achievable, and on the other hand, if it comprises more than 22.0%, a large amount of large primary /3
crystal Si is formed, and refining to a small size and elimination become difficult even if the Sr addition and selection of specific casting conditions are carried out, thus causing deterioration of forgeability, mechanical properties, etc. Therefore, the Si content is set in the range of 7.5-22.0%.

Cu is a component for improving mechanical properties as well as wear resistance; if it comprises less than 3.0%, no effect can be seen. On the other hand, if it comprises more than 7.0%, the amount of Al-Cu type products crystallized out is increased, it becomes difficult to eliminate them by means of thermal treatment carried out after casting, and consequently, the forgeability and mechanical properties are deteriorated. Therefore, the Cu content is set in the range of 3.0-7.0%.

Mg is also a component for improving mechanical properties as well as wear resistance; if it comprises less than 0.3%, no effect is seen; on the other hand, if it comprises more than 1.0%, it becomes difficult to eliminate the Al-Mg-Si type crystallized products by means of thermal treatment carried out after casting, and consequently, the forgeability is deteriorated. Therefore, the Mg content is set in the range of 0.3-1.0%.

Fe and Mn are components that have approximately the same effects and improve the wear resistance by promoting the formation of microscopic eutectic Si and Si-type crystallized products at the time of casting. If each comprises less than 0.25%, no effects can be seen, and on the other hand, if they comprise more than 1.0%, the crystallized products of Al-Fe-Mn or Al-Fe-Mn-Si type compounds are liable to become very large, such that it is extremely difficult to eliminate them during casting, thus causing the forgeability to deteriorate. Therefore, the Fe and Mn contents are set in the range of 0.25-1.0%, respectively.

Sr is a component for eliminating the crystallized products of Al-Fe-Mn-Si compounds, as well as for refining Si primary crystal and eutectic Si so as to improve the forgeability by adding it to the above composition of those components and casting under suitable casting temperature and cooling conditions, explained later. If it comprises less than 0.005%, such an effect cannot be seen, and on the other hand, if it comprises more than 0.1%, a pedatifid Sr compound is formed, thus causing internal defects and mechanical properties to deteriorate. Therefore, the Sr content is set in the range of 0.005-0.1%.

Those components described above are the essential required components, but one or more kinds of Ti: 0.001-0.05%, Ni: 0.3-2.0%, Cr: 0.05-0.4% and Zr: 0.05-0.25% can be added if necessary. Regarding the above contents ranges, Ti is effective for refinement and stabilization of the mechanical properties, Ni provides heat resistance and high-temperature strength, and furthermore, Cr and Zr are effective for improving wear resistance.

Incidentally, the aluminum alloy of the above composition contains unavoidable impurities, which are allowed as long as they will not damage the effects of this invention.

The aluminum alloy of the above composition can be melted using conventional procedures. However, in this invention, the casting is carried out under the following conditions, and, after casting, a thermal treatment is carried out under specific conditions.

Specifically, the casting of the above aluminum alloy is carried out with a suitable process such as ingot casting, continuous casting, etc., but if the casting of the aluminum alloy of the above component system (with no Sr) is carried out with conventional procedures as previously, a slow-cooling structure is formed. This structure is, as shown in Figure 15, a structure comprising Al-Fe-Mn-Si crystallized products (typical composition: 60% Al-12% Fe-18% Mn-10% Si), Si primary crystal, eutectic aluminum phase and aluminum dendrites. Incidentally, in the figure, the large black portion on the left shows Al-Fe-Mn-Si crystal, the slightly smaller black portion at the center is Si primary crystal, the bottom center portion shows aluminum dendrites, and the other portions are eutectic aluminum phase or Si phase (eutectic Si).

With respect to the size of these components, the Al-Fe-Mn-Si crystal is often as large as 100 μm, and the Si primary crystal and eutectic Si can grow to 50 μm or larger, thus inhibiting wear and forgeability. In the previous art, these very large crystallized particles are refined to a somewhat smaller size during the extrusion stage after casting, but such an effect is not guaranteed in the forging stage of the casting-forging process.

Therefore, in this invention, the formation of these very large crystallized particles is inhibited by carrying out a thermal treatment after casting or forging, and the respective process is controlled so that the size of the crystallized products formed is smaller than 20 μm. This requires regulation of cooling /4

rate and casting temperature (to be explained later) when casting with the above composition and control thermal treatment conditions.

First of all, in the case of cooling rate at the time of casting, the sizes of Al-Fe-Mn-Si compounds, experiments carried out by the present inventors found that the sizes of Si primary crystal and eutectic Si and coarseness of aluminum dendrites could be controlled by quenching in the respective temperature ranges of crystal growth. Specifically, it is necessary in this invention to carry out cooling at least from 670-554°C at a cooling rate of 5°C/sec or faster.

Specifically, (a) The growth of the Al-Fe-Mn-Si crystallized products is in the temperature range of 670-554°C, and if the cooling is carried out at a rate of 5°C/sec or faster in this temperature range, it is possible to control the size of crystals to below 20 μmm [sic] as shown in Figure 1.

Furthermore, (b) the growth of Si primary crystal is in the temperature range of 670-554°C, and if the cooling is carried out at a rate of 5°C/sec or faster in this temperature range, it is possible to control the size of crystals to below 20 μm as shown in Figure 2.

In addition, (c) there is a correlation between the size of eutectic Si and aluminum dendrite arm spacing as shown in Figure 3, and with this dendrite arm spacing (abbreviated to DAS, below) as an index, it is possible to control the size of eutectic Si. On the other hand, DAS can be reduced by increasing the cooling rate as shown in Figure 4. Therefore, as is apparent from the results shown in Figures 3 and 4, if the cooling rate is 10°C/sec or faster, DAS is less than 10 μm, and it is possible to refine the eutectic Si size to below 15 μm.

To satisfy the requirements of (a)-(c) described above, the cooling in this invention is carried out at a cooling rate of 5°C/sec or faster for 670-554°C and 10°C/sec or faster for 568-554°C.

On the other hand, the casting temperature is a factor markedly affecting the size of Al-Fe-Mn-Si crystallized products. As described above, the crystallization temperature and growth temperature of the

Al-Fe-Mn-Si crystallized products are in the range of 670-554°C; the cooling in this temperature range has to be carried out at a cooling rate of 5°C/sec or faster, and to realize this cooling rate, it is necessary to regulate the casting temperature properly.

First of all, the method for determining the minimum temperature required for casting is explained by referring to Figure 5 below.

The figure shows the effect of the casting temperature on the cooling rate in the temperature range of 670-554°C. In this case, if the temperature of molten aluminum alloy inside a tundish coming into contact with the mold is T_1, which is below 670°C, the cooling rate R of the molten mixture in a temperature range of 670-554°C is represented by $R = (670\text{-}554)/t_1 = 116/t_1$ (°C/sec) (where t_1 is cooling time (sec) from T_1 to 554°C). This t_1 is generally longer than 30 sec, and the above cooling condition required is hardly satisfied at this casting temperature of T_1.

If the temperature of the molten mixture is above 670°C, for example, 690°C, the cooling rate R in the temperature range 670-554°C is represented by $R = (670\text{-}554°C)/t_2$ (where t_2 is cooling time (sec) between 670-554°C). Therefore, if t_2 is set below 23 sec, R is higher than 5°C/sec, it is possible to control the growth of the Al-Fe-Mn-Si crystallized products, and thus, this temperature, that is, a temperature above 670°C, is the minimum casting temperature required.

On the other hand, the higher the upper limit of the casting temperature, the better, as in the case of T_3 shown in Figure 5, and, regarding crystallized product formation and growth, there is no special restriction required. However, if the temperature is above 850°C, absorption of gas (H_2) is liable to become substantial and is liable to form pinholes, blow holes, etc., in the cast ingot, thus markedly reducing the product quality of the cast rod prepared. Therefore, the upper limit is suitably 850°C.

Incidentally, the nucleus formation and crystalline growth of Si primary crystal are carried out in about the same temperature range as that of the above Al-Fe-Mn-Si crystallized products. Therefore, by

selecting the above casting temperature range it is possible to prevent Si primary crystal particles from becoming very large.

As described above, if a suitable amount of Sr is added to the aluminum alloy of the above chemical composition, and the casting is carried out similarly, it is possible to eliminate the crystallized products of Al-Fe-Mn-Si compounds and Si primary crystal.

The conditions of the thermal treatment carried out after casting in this invention as explained below. /5

The cast rod prepared under the conditions described above contains Al-Cu and Al-Mg-Si type crystallized products; furthermore, the eutectic Si has an angular structure, and consequently, the effect improving the forgeability may not be sufficient. As a result of experiments carried out by the present inventor, it was found to be possible to eliminate the crystallized products of Al-Cu and Al-Mg-Si type compounds, allow eutectic Si to become particles, and markedly improve the forgeability by carrying out a thermal treatment of (450-510°C) x (2-12 h) for the cast rod prepared as described above. Incidentally, such an effect cannot be achieved if the temperature and time are outside the above ranges.

After the cast rod has undergone the thermal treatment as described above, it contains refined sizes of inevitably present crystallized products of smaller than the 20 μm of the diameter of circumscribed circle, with eutectic Si particles becoming microscopic, and furthermore, aluminum dendrite space (branch spacing) being restricted to below 10 μm. Therefore, the forgeability and wear resistance are excellent.

This invention is explained specifically in detail with application examples below.

Application examples

Aluminum alloys of the chemical compositions shown in Table 1 were melted using conventional procedures, and continuous casting under the casting conditions (casting temperature and cooling rate)

shown in Table 2 was carried out to obtain cast rods approximately 30 mm in diameter. After casting, the thermal treatment was carried out under the conditions shown in the table.

Mechanical properties were examined for the prepared cast rod samples, and forgeability and wear resistance were evaluated at the same time. Furthermore, the sizes of crystallized products and DAS (dendrite arm space) were measured. The results obtained are shown in Table 2.

Incidentally, the wear resistance was measured with an Ohkiwa wear-resistance tester with a wear rate of 1.0 m/sec and load of 3.2 kg, and the results indicate relative amounts of wear. Furthermore, the forgeability was evaluated by cold forging of test pieces–10 mm diameter x 20 mm long–with a processing rate of 50%. The results are indicated with O for no crack generation, ◎ for no crack generation up to 60% of processing rate, and X for crack formation with a processing rate below 50%.

TABLE 1. Chemical component (wt%)

① 区分	No	Si	Cu	Mg	Fe	Mn	Sr	Ti	Ni	Cr	Zr	その他 ④
② 本発明例	1	10.93	4.50	0.82	0.43	0.46	0.005	0.088	—	0.005	—	Al残部 ⑤
	2	〃	〃	〃	〃	〃	0.01	〃	—	〃	—	〃
	3	〃	〃	〃	〃	〃	0.03	〃	—	〃	—	〃
③ 比較例	4	10.53	4.78	0.77	0.44	0.38	—	0.021	—	0.017	—	Al残部 ⑤
	5	〃	〃	〃	〃	〃	0.15	〃	—	〃	—	〃

Key: 1 Classification

2 Example of this invention

3 Comparative example

4 Other

5 Aluminum remainder

TABLE 2. Aluminum alloy cast rod production conditions and characteristics /6

(1)	No.	(2)	(3) (4)	(3) (5)	(6)	(7) (μm)	DAS (μm)	(8)	(9)	(10)	(11)
(12)	1	1	760℃	7℃/sec	475℃×8hr	15	8	20	○	47.5	17.4
	2	2	″	″	″	10	7	20	◎	47.3	17.2
	3	3	″	″	″	6	5	23	◎	48.2	17.6
(13)	4	4	760℃	15℃/sec	475℃×8hr	25	30	18	×	46.9	14.3
	5	5	″	7℃/sec	″	4	4	24	×	45.8	16.5

(Note) Relative amount of wear ($mm^3/kg \times 10^{-7}$) used for evaluation

Key:
1 Classification
2 Sample Alloy No.
3 Production condition
4 Casting temperature
5 Cooling rate
6 Thermal treatment
7 Crystallized product size (μm)
8 Wear resistance (Note)
9 Forgeability
10 Tensile strength (kgf/mm^2)
11 Fatigue strength (kgf/mm^2)
12 Example of this invention
13 Comparative example

As is apparent from the results shown in Table 2, the examples of this invention show excellent wear resistance, and at the same time, the strength and forgeability are also satisfactory.

Figure 6 shows the structure of the cast rod of the example No. 3 of this invention before thermal treatment; it shows no presence of Al-Fe-Mn-Si crystallized products and Si primary crystal and small

DAS compared with Comparative Example No. 4 (Figure 7) with no Sr addition and Comparative Example No. 5 (Figure 8) with Sr added in an excessive quantity.

Furthermore, Figures 9 and 10 shows the structure of Example No. 3 of this invention before and after thermal treatment. Before the thermal treatment, the structure has eutectic Si in an angular state as shown in Figure 9, but after the thermal treatment, the structure becomes granular as shown in Figure 10.

Furthermore, with respect to DAS, Example No. 3 of this invention has DAS inhibited below 10 μm as shown in Figures 11 and 12, whereas in the case of not satisfying the production conditions of this invention in Comparative Example No. 4, the structure includes spacing reaching 12 μm and very large eutectic Si as shown in Figures 13 and 14.

Effect of the invention

As described above in detail, the casting and thermal treatment are carried out under special conditions in this invention for an aluminum alloy of a specific chemical composition with a suitable amount of Sr added, the crystallized products formed are controlled to microscopic granular sizes, and the structure shows small aluminum dendrite arm spacing. As a result, it is possible to obtain a high-quality aluminum alloy cast rod having excellent wear resistance and satisfactory forgeability, strength, fatigue life, etc.

Brief description of the figures

Figure 1 is a drawing showing the effect of cooling temperature on the Al-Fe-Mn-Si size in the temperature range of 670-554°C;

Figure 2 is a drawing showing the effect of cooling rate on the Si primary crystal size in the same temperature range as above;

Figure 3 is a drawing showing the relationship between dendrite arm space (DAS) and eutectic Si size;

Figure 4 is a drawing showing the effect of cooling rate on DAS in the temperature range of 568-554°C;

Figure 5 is a drawing showing the effects of casting temperature on the cooling rate in the temperature range of 570-554°C;

Figures 6, 7 and 8 are micrograms (x200; x500 for Figure 8) showing the metal structures of cast rods related to the addition of Sr, Figure 6 shows the case of Sr addition, Figure 7 shows the case of no Sr addition, and Figure 8 shows the case of Sr addition in excess;

Figures 9 and 10 are micrograms (x200) showing metal structures of cast rods related to the thermal treatment after casting, Figure 9 shows the case before the thermal treatment, and Figure 10 shows the case after the thermal treatment;

Figures 11-14 show the states of DAS size distribution in cast rods (Figures 12 and 14) and micrograms (x200) of metal structures (Figures 11 and 13), Figures 11 and 12 show the case of this invention, and Figures 13 and 14 show the case of the comparative example; and

Figure 15 is a microgram (x200) of metal structure (slowly cooled structure) obtained by slowly cooling from the casting temperature of an aluminum alloy of the composition of this invention.

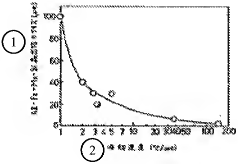

Figure 1

Key: 1 Al-Fe-Mn-Si crystallized product size (µm)

2 Cooling rate (°C/sec)

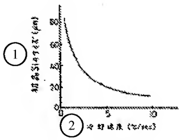

Figure 2

Key: 1 Si primary crystal size (µm)

2 Cooling rate (°C/sec)

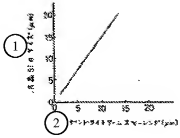

Figure 3

Key: 1 Eutectic Si size

2 Dendrite arm spacing (μm)

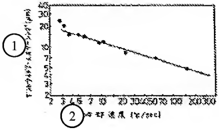

Figure 4

Key: 1 Dendrite arm spacing (μm)

2 Cooling rate (°C/sec)

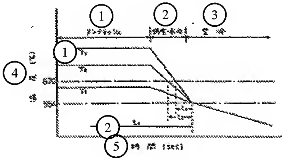

Figure 5

Key: 1 Tundish

2 Water-cooled mold

3 Air cooling

4 Temperature (°C)

5 Time (sec)

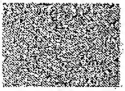

Figure 6

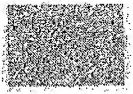

Figure 7

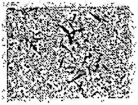

Figure 8

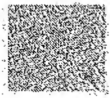

Figure 9

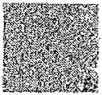

Figure 10

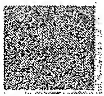

Figure 11

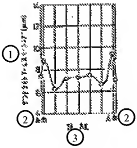

Figure 12

Key: 1 Dendrite arm spacing (μm)

2 Surface

3 Distance

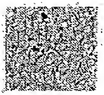

Figure 13

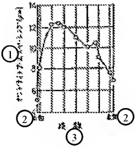

Figure 14

Key: 1 Dendrite arm spacing (μm)

2 Surface

3 Distance

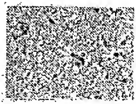

Figure 15